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DISCUSSION OF PRINCIPLES OF HIGHWAY CAPACITY RESEARCH

(Published in November, 1951)

By E. L. Fieldhammer, and O. K. Normann

HIGHWAY DIVISION

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DISCUSSION

E. L. FIELDHAMMER,[3] J. M. ASCE.—Extensive use of *The Highway Capacity Manual*,[2] to which Mr. Normann refers, during the design of an expressway facility, proved it to be an invaluable aid in determining the geometric requirements of the expressway itself, as well as the capacity of the city street system into which the expressway traffiic emerged.

However, in attempting to "***compare the capacity of an entire street system, as it is being operated, with the present or estimated future traffic demand" (see under the heading, "Interrelation of Design Elements"), the writer frequently encountered two interrelated problems for which no solution was readily available, either in *the Manual* or elsewhere, namely: (1) The determination of the capacity of an unsignalized intersection and (2) the lack of a signal control warrant based on intersection capacity. The first of these problems would seem to offer opportunities for further research. It will, therefore, be presented here in the hope that some large organization with adequate facilities will deem it a worthwhile project since the massive volume of data required before a conclusion can be reached on a matter such as highway capacity prevents an individual from undertaking the research himself. The second problem will be discussed also since the two are not readily separable.

These problems usually occurred in the following manner: An intersection would be encountered which did not satisfy any of the warrants for signal control given in *The Manual on Uniform Traffic Control Devices for Streets and Highways*.[4] However, if such an intersection were analyzed under the assumption that it was signalized, the result would indicate that the intersection was operating at, or near, its practical (and sometimes, its possible) capacity. That is, the total time required for all movements would approach 100%.

In an attempt to determine, rationally, the reasons for the foregoing result, it appeared that the signal-control warrants bore little relationship to the capacity of the intersection, and that the unsignalized capacity was larger than the signalized capacity of a given intersection. Although, in the absence of any data, there were at least three distinct possibilities for the relationship of the capacities of signalized and unsignalized intersections:

1. The unsignalized capacity of an intersection was larger than the signalized capacity (a very limited number of observations tend to favor this theory);
2. The signalized and unsignalized capacity of an intersection were the same, within the limits of accuracy of traffic calculations; and
3. The signalized capacity of an intersection was greater than the unsignalized capacity.

NOTE.—This paper by O. K. Normann was published in November, 1951, as *Proceedings-Separate No. 105*. The numbering of footnotes in this Separate is a continuation of the consecutive numbering used in the original paper.

[3] D. B. Steinman, New York, N. Y.

[2] "Highway Capacity Manual," by the Bureau of Public Roads, U. S. Dept. of Commerce, Washington, D. C.

[4] "Manual on Uniform Traffic Control Devices for Streets and Highways," by the Bureau of Public Roads, U. S. Dept. of Commerce, Washington, D. C., 1948, Sections 159, 207–213, 234, 253.

Since a measure of the capacity of unsignalized intersections was not available, the following method of analysis, utilizing possibility 2, was applied whenever unsignalized intersections were encountered:

a. The capacity of the intersection approaches was determined on the basis of the capacity charts and procedures for signalized intersections, as given in *The Highway Capacity Manual*, and elsewhere[5];

b. The actual traffic on each approach was compared with the capacity to determine the time required for each movement;

c. If the time required totalled, say, 85% to 100%, signal control was warranted; and

d. If the time required by any one approach was less than 20%, but the total time was within the 85% to 100% range, traffic actuated equipment was considered.

If possibility 1 were true, and a measure of unsignalized intersection capacity were available and had been substituted in step *a*, the procedure outlined would have resulted in a reduction of intersection capacity below actual flow upon the installation of signal control. This hardly seems desirable.

If possibility 3 were true, on the other hand, and a measure of unsignalized capacity had been used in step *a*, the resultant warrant would be most satisfactory since it would establish signal control and thus increase capacity as the unsignalized intersection approached its maximum flow.

Were a measure of the capacity of unsignalized intersections available, comparison of it with the capacity of signalized intersections would decide whether possibility 1, 2, or 3 corresponded most closely to actuality. Once this was established it would be possible to analyze an unsignalized intersection and determine its influence upon the traffic flow of a city street system. It would also enable the traffic engineer to apply a realistic warrant for signal control, based on intersection capacity, as well as to have some foreknowledge of the result of its use. Thus it appears that research leading to a measure of the capacity of unsignalized intersections would be fruitful.

O. K. NORMANN[6].—The remarks of Mr. Fieldhammer enlarge upon the subject matter of the paper beyond its originally intended scope; nevertheless, they are very pertinent. Of the three assumptions listed by him, only one can be valid for any particular intersection, but that one might be any of the three, depending upon the conditions at the intersections. Thus there are three classes of intersections, the first of which has an unsignalized capacity greater than if signalized. An example of this class would be a multi-lane arterial way on which relatively high speeds prevail (where unsignalized), intersecting a minor cross street on which traffic is comparatively light. Such intersections occur most frequently in surburban areas. The free-flowing volume on the arterial way may be greatly in excess of the volume that could be accommodated if the movement were interrupted for even a very short interval of time by a traffic signal. If a traffic signal should be installed for any one or

[5] *Public Roads: A Journal of Highway Research*, Vol. 26, No. 6, February, 1951.

[6] Chf., Section of Traffic Operations, Bureau of Public Roads, U. S. Dept. of Commerce, Washington, D. C.

more of several reasons (such as failure of drivers on the arterial highway to yield the right of way to traffic on the minor street), the capacity of the major highway would be diminished. Should there be an insufficient increase in the volume on the cross street to offset the loss to the arterial way, the capacity of the intersection would be decreased as a result of the installation. Furthermore, the average delay per vehicle would be increased. Despite such economic losses, however, installations of this type are commonplace, and traffic departments throughout the United States are besieged with requests for still more.

In many instances, however, the capacity of the major facility is controlled by major intersections at other locations. In such a case, the installation of a traffic signal at intermediate locations at minor roads might actually improve the traffic flow on the major facility if the signals are properly sychronized.

The second assumption is believed to be correct for most intersections where streets are of moderate or narrow width and where vehicular speeds are relatively low, so that a driver wishing to enter the intersection from the cross street may feel reasonably sure that through traffic will yield the right of way and that the possibility of serious accident is slight. Another requirement would be that the traffic demand be less than the possible capacity of the intersection. If not, the intersection would most likely become completely blocked and traffic on all the approaches would come to a standstill.

Should the volume of traffic approaching any intersection exceed that which is able to clear the intersection—that is, if it exceeds the possible capacity of the intersection—the third assumption would apply. It is a fundamental principle of highway capacity that, when the number of vehicles attempting to use a facility exceeds the capacity of that facility under the prevailing conditions, traffic at some point will be at a standstill. The unregulated entry of vehicles into an intersection, may cause a demand exceeding the possible capacity of the intersection, with the result that the volume of traffic will reduce to zero and remain there until orderly movement has been restored. In most instances, a traffic signal will prevent the occurrence of complete congestion within the intersection and thereby improve its capacity when the volume is at or near its possible signalized capacity. Such was doubtless the objective in the initial development of traffic signals, which performed this mission so well that the signal was soon regarded as a panacea for all traffic ills. In retrospect, this may have been unfortunate in the sense that if signals had not become so commonplace it is conceivable that more attention might have been devoted to the development of proper speed-zoning regulations, more realistic right-of-way rules, and the invention of other regulatory measures or devices that would have aided the flow of traffic at less hazard and without so seriously impairing street capacities.

Accepting the theory that signals may either increase, decrease, or fail to alter the capacity of an intersection—depending upon the prevailing conditions—the question remains as to what application can be made of this knowledge. Except in so far as it may be of value in basing a signal warrant on intersection capacities, this question is perhaps of academic interest only. As a practical matter most intersections for which the traffic volume is sufficiently heavy to justify an investigation of their capacity are either signalized

or will become signalized. As soon as the volume of traffic at an unsignalized intersection approaches its capacity as a signalized intersection, signalization is almost certain to take place. There is little likelihood that the signal will be removed from any intersection that is already signalized. In short, if an intersection is unsignalized at present it probably will become signalized before its capacity is reached, and, if it is already signalized, it will probably remain that way. Hence, the engineer, in computing capacities, should regard intersections as being signalized, whether or not the signal actually has been installed. Aside from capacities his primary concern will be in signal warrants so that he can estimate the date at which a signal will be required.

In the itemized steps *a* and *b* of his procedure, Mr. Fieldhammer has outlined a method for allocating the green time for an imaginary signal installed at an unsignalized intersection. Once this has been accomplished, computation of the capacity of the intersection as if it were signalized is a relatively simple operation. As to the volume for which signal control is warranted, there appears to have been far too little factual research, but the proposal of Mr. Fieldhammer in item *c* seems realistic and plausible. For some time, it has been the writer's contention that the traffic volume warrants for signal installations should be based on the relation between the traffic demand and the possible capacity of the intersection. The 85 percentile that Mr. Fieldhammer suggests may be desirable at intersections involving a major and a minor facility. With the traffic flow more evenly divided on the two facilities, however, it would seem that a signal would be warranted at the intersection of two two-lane roads when the demand is less—possibly approximating 60% of the intersection's capacity—and at a considerably lower percentage for the higher-capacity facilities with two or more traffic lanes for each direction of travel.

In most instances where actuated control is at all feasible, better allocation of signal time can be obtained by using this device than is possible with fixed-time control. Mr. Fieldhammer proposes that, if the time required by any one approach is less than 20%, traffic-actuated control should be considered. It is doubtful that he intends to restrict consideration of traffic actuation within this limit, however, but rather to insure against the use of short green intervals of the order of 10 sec or 15 sec. Such practice is commendable, as green intervals shorter than 20 sec are undoubtedly less efficient than the longer intervals, and it is questionable whether the curves of Fig. 24 of *The Highway Capacity Manual*[2] can be applied properly where the green interval is shorter than 20 sec. At fixed-time installations it is sometimes practicable to adhere to the 20-sec minimum while retaining a low percentage of the total time by lengthening the total cycle. This is particularly true at isolated intersections. Instances are known of 100-sec cycles that have had little or no objection voiced against them.

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